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# Evaluation and Separation of IKONOS Sensor's CCD Noise From Dark Object

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**Abstract—Identifying target signals have always been considered as one of the most important issues in the field of satellite image processing. Signals received from satellite sensors include some signals other than those of target signal that may be classified totally as the atmospheric effect and the sensor induced noise. One method for measuring and removing non-target signals is that of atmospheric correction by *Dark Object Subtraction* (DOS). This method is based on the sensor's output for the targets that should have almost zero reflectance in a given band. Next, the obtained value will be deducted from the remaining pixels values; regardless of the type of the sensors.Each *Charge-Coupled Device* (CCD) has its own noise behavior; therefore, the amount deducted values from each pixel can be different for each CCD unit and type. The data were obtained from multispectral sensor images of IKONOS. The results of this study showed that the amount of dark object pixels and the total amount of CCD noises in each band are different. Separation of the noises introduced from the amount of dark object pixel values can result in an upgraded method for image atmosphere corrections.**

**Keyword — IKONOS, CCD, Noise, Atmosphere correction**

## 1. Introduction

The quality of satellite images has always been of particular importance in remote sensing. Signals received from satellite sensors; often include some signals other than target signals, the group of which are defined as non-target signals. This includes sky radiance and path radiance [1]. To this we can add the sensors electronic noise. One method for measuring and removing non-target signals is that of atmosphere correction through the use of dark objects where the amount of energy emitted (radiance or reflectance) from some earth targets in certain wavelengths, is close to zero [2].The smallest value in each band of the image with a cover of forests (green and blue) and water bodies (red and near infrared) represents the DN value of dark object [3], [4]. It is often preferred this approach to radiative transfer model for eliminating the effect of atmosphere. That is because in the radiative transfer model, measuring the water vapor in the air along with the aerosols as well as describing atmospheric conditions along with collecting earth data is difficult. Nonetheless, from a practical standpoint, the smallest amount of DN may also contain errors. That is because selection of the dark object value is based on a visual examination from the histogram values. Another error in dark object values as used for atmosphere correction –which is discussed in this article - is the sensor noise. Despite these errors, dark object subtraction technique has always been a good correction for the atmospheric effect on remote sensing data [3].

Separating the non-target signals from the sensor electronic noise is necessary. The noise of each CCD has a unique value. Therefore, by changing the sensor, the CCD characteristics and the noise value changes. Nevertheless, some CCD noises affect the image much more than the others. They are investigated in this study. Noises like dark current noise, non-uniform pixel and read noise are examples of these noises which are discussed here.

The world's first commercial satellite was launched on September 24, 1999 with the name of IKONOS. IKONOS collects images at an elevation angle of greater than 15 degrees and the azimuth unrestricted. Because the orbit is sun synchronous, all imagery is collected at approximately 10:30 a.m. local solar time [5]. Images analyzed in this study were collected by the IKONOS sensor. This sensor can provide images in two forms of Panchromatic (PAN) and Multispectral (MS). IKONOS is a high-resolution satellite that provides Panchromatic images with a resolution of 1 meter and MS images with a resolution of 4 meter.

In this study, first a dark object in each image band is identified. The value of pixels in each band is then calculated. Next, the specified noises for each band are calculated separately. Each of these noises has different effects on image pixel values. Separating these noises from the dark object ones; makes it possible to predict electronic noise via changing the sensor, and to obtain a constant value for the sensor noise values.


Fig(1). Separating image into green and near infrared bands: the right image represents a body of water in the near infrared band and the left one shows trees in the red band.

## 2. Dark Object

Among the common atmospheric correction methods, Dark Object Subtraction (DOS) is a simple and yet usefulone to eliminate the effect of the atmosphere from images,especially when limited ground information is available[6]. To obtain the dark object, IKONOS should seek zero reflectance surface covers. In order to achieve zero reflectance pixels in the green and blue bands, tree shades, and in the red and infrared bands, water body can provide the dark object. The IKONOS image used in this work is an MS one from Quds town near Tehran. One of the main reasons for having chosen this region is that the image contains both forests and water bodies. In Figure 1, these scenes are shown in two bands of near infrared and green. Taking a look at the images, one can realize that, for example, the body of water in the infrared band and shade of dense trees in the green band seem dark.

## 3. CCD Noises

The imaging system CCD can usually be demonstrated by three sub-systems. First, the CCD arrays convert photons within each pixel into electrons and voltage. Second, the electronic part of the camera performs a non-linear compression of the voltage values. Finally, the third sub-system is the Analog to Digital Converter (A/D) that generates digital image. During the process of converting radiation to digital image, various electronic noises enter into the system. In this paper, we investigate three noises, i.e. dark current noise, non-uniform pixel noise and Read noise, the first two of which are from CCD array noises and the last one is from CCD read circuit noises.

Image obtained from the dark object ($E_{DOS}$) includes electronic sensor noise in addition to atmosphere effect ($E_{at}$). The three noises can be modeled as a theoretical relation as follows:

$$E_{DOS} = N_{non}\, E_{at} + N_{dark} + N_{read} \qquad (1)$$

$N_{non}$ is non-uniform pixel noise known as fixed pattern noise that appears as a constant factor in the image. Another noise that is added cumulatively, is the dark current noise shown as $N_{dark}$ in the equation. $N_{read}$ is read noise related to CCD circuit read out. That is added as constants to the image pixels.

### 3.1. Dark Current Noise

This noise is the result of electrons generated by high temperature at the CCD and has always been one of the main challenges of CCD noise [7], [8]. To identify and eliminate dark current noise, the dark frame method is usually offered. In this method, in order to have a dark frame, conditions should be provided that prevent light from reaching the CCD. Dark frames should be prepared at the same temperature and time as the original image, because the dark current value is changes linearly with time and also the CCD temperature affects the amount of this noise [9]. The DN value of each pixel of dark frame (which can be positive or negative) shows the dark current noise [11], [10]. One of the stages of IKONOS relative radiometric calibration is the measurement of dark current noise using dark frames. This process is measured by camera with closed door during satellite flight and is shown in all band and for each detector by curve [12].

### 3.2. Non-Uniform Pixel Noise

This type of noise is generated as a result of pixel-to-pixel variations in the CCD response to non-uniformity of detectors in a uniform light [13], [7], [9]. To remove and measure this noise, flat-field techniques is one of the most and efficient method proposed. For preparing flat-field frames, different methods should be used to create a uniform light. For relative radiometric calibration and measurement of non-uniform noise of the CCD pixel based on IKONOS satellite, side-slither imaging techniques of a homogeneous earth target (desert, snow and ice) is the method used for this sensor. This method uses a 90-degree rotation of the focal plane to place focal arrays coordinated with and parallel to the orbital path rather than perpendicular to it. This will force all detectors to see the earth surface like a single detector.Array is scanned lengthwise such that each detector observes the same point on the ground. Therefore, more uniform statistical information is collected from the target compared to regular push broom collection [14].

### 3.3. Read Noise

Another source of noise that is inherent in all CCDs is read noise which is considered as an important CCD noise particularly for low-intensity images. In principle, this type of noise can be classified as time noise, because the random motion of a particle change over time [7]. Read noise is typically defined for a number of electrons in the process of converting input signal to output voltage [15] and consists of two inseparable components. First, is in the Analog to Digital Signal conversion process, where it is believed that every amplifier chip and A/D circuit converter produces a statistical distribution of possible responses with the focus on the mean value (Gaussian distribution), although the statistical distribution of this value is not necessarily Gaussian .Thus, even in a hypothetical case, if a pixel is reading out the same pixel twice, each time with identical charge, the answers can be slightly different. Second, the output electronic circuits produce fake electrons that will create unwanted random fluctuations in the output. These two effects are combined and create uncertainty in the final value of the pixel output. The average value of the uncertainty is called read noise that is controlled by the electronic properties of the amplifier range output and output electronic [7].

Before computing the read noise some information about the parameters with significant impact on the noise must be available. Three factors affect the results, i.e. CCD gain, flat-field image and bias frames. Zero image or bias frame enables us to measure zero noise level from one CCD. To avoid negative values in the output image, electronic of CCD with one offset is set up. This amount of offset level names bias. One common way to assess the level of bias is to use bias frames. Method of obtaining bias frames is similar to that of dark frames. Thus taking image should be done in dark conditions (shutter closed) and in the shortest possible time (depending on the camera ability). Of course if more than one bias frame is needed, images should be obtained at the same temperature [9], [10]. Flat-field frames are described in the non-uniform noise pixels. Now let's see how bias and flat field frames can determine the gain rate and read noise. First, a mean value of the pixels of a flat field and bias is calculated and are respectively named $F^{-}$ and$B^{-}$. In the next step, the standard deviation of the measured images (shown as $\boldsymbol{\sigma_B}$ and$\boldsymbol{\sigma_F}$) will be calculated. The standard deviation can be obtained from the following equation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \qquad (2)$$

Where N is number of pixels, μ is mean of pixels and $x_i$ is noise in each pixel.

After we obtain standard deviation of bias image and flat-field, the following equation is used to calculate the gain:

$$\text{Gain} = \frac{F^{-} - B^{-}}{\sigma_F^2 - \sigma_B^2} \qquad (3)$$

Where $\sigma_F^2$ and $\sigma_B^2$ are variance of flat field and variance of bias respectively.

Finally, the read noise is calculated from the following equation:

$$\text{Read noise} = \frac{\text{Gain}.\,\sigma_B}{\sqrt{2}} \qquad (4)$$

At the end, it should be noted that adding items to amplifier design, pixel output synchronizers and different semiconductor designs can be used to increase the electronic output efficiency. Different methods of producing integrated circuits help to improve the read noise function.

## 4. Results and Tables

The device evaluated in this paper is CCD based on the IKONOS sensor. The data used in this study include IKONOS MS images one from Quds town near Tehranas well as Imagery collected while array is being scanned lengthwise across uniform scene (side slither) and standard images taken with the door closed (dark frame)

As a value for non-uniform pixel noise and dark current noise, the average curve obtained for each wavelength and in all detectors (figure 2 and figure 3) can result in non-uniform and dark current value for IKONOS CCD,the results of which are shown in Table 1. Also Noise removal algorithm is shown in Figure 4.

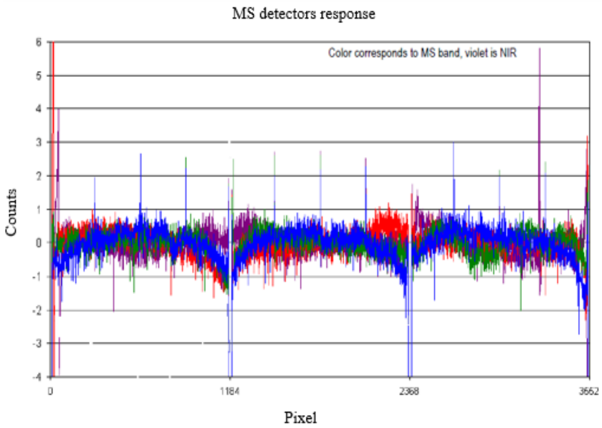


Fig (2). Non-uniform pixel noise for IKONOS MS detector [16]

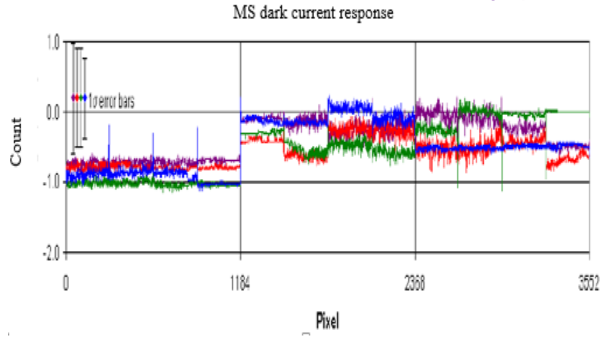


Fig (3). Dark current noise for IKONOS MS detector [16]

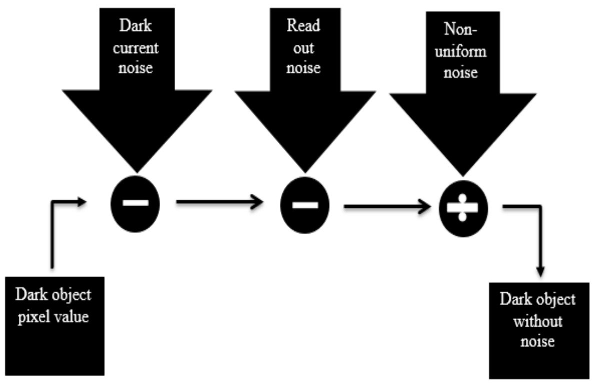


Fig (4). Removal algorithms for dark current noise, read noise and non-uniform noise from dark object

Table (1). The values of electronic noise and dark objective pixel at four MS IKONOS bands

| Band / Noise | NIR | Red | Blue | Green |
|---|---|---|---|---|
| Dark object DN | 66 | 258 | 162 | 292 |
| Dark current | -0.34 | -0.5 | -0.3 | -0.63 |
| Non-uniform | -0.23 | -0.02 | -0.01 | 0.04 |
| Read out | 0.01 | 0.09 | 0.09 | 0.35 |

## 5. Discussion and Conclusions

The main objective of this paper is to differentiate and measure IKONOS sensor electronic noises from atmospheric corrected images. Though, measuring all satellite electronic noises is hard or impossible, in this study, it is tried to assess some important CCD noises on their circuits that may have far greater impacts than any other noise on the images from satellites. As can be seen in Table 1, the DN values of dark object and noises investigated in 4 bands of IKONOS MS images are shown. Although, dark object technique is one way to remove the atmospheric effects and other sensor noises, by separating electronic noise and atmospheric effects, however it is wise to change CCD and the related circuits to simultaneously estimate the effect of atmosphere on the received image.

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